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Forecasting Turbine Icing Events

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Abstract

The occurrence of icing on wind turbines has been identified as an important issue when siting turbines in cold climates, due to the potential for production loss, structural fatigue and health and safety issues. The ability to forecast turbine icing could help to minimize these risks by helping to identify sites which are prone to excessive icing before they are constructed, and by aiding in the forecasting of short term production estimates.

In this study, we focused on two wind farms in Europe with known icing events, to determine how well our method could identify periods of either reduced production or turbine identified icing. The icing model used was based upon current physical icing model methods, and received inputs from the WRF mesoscale model. The periods of icing were able to be detected reasonably well at the warmer site, however the model did not accurately remove ice from the colder site. Both locations demonstrated a need for additional investigation into ice removal mechanisms in the model.

In addition to the model evaluation we were able to investigate the potential occurrence of ice induced power loss at two wind parks in Europe using observed data. Through this study we found that there is a large spread in the amount of icing experienced by the various turbines. Evaluating and adding these differences to the model will be undertaken as future work.

Introduction

Case studies of icing occurrence at two wind farms were performed utilizing the ice forecast model in development.

The first farm (A) is located in a mountainous area on the Iberian Peninsula, and the case study evaluates a 10 day long period with a known icing event. The turbine status indicated when icing was occurring based on an internal algorithm.

The second farm (B) is located in a forested region of Sweden which is relatively flat. This study looked at January 2011. This farm did not have icing detection.

Methods

- For observations we use:
  - Wind Speed, Normalized Power, Temperature, Turbine State (A Only)
  - Estimated power from nacelle wind speed & generic power curves
- The icing model is based on:
  - Forced by WRF mesoscale model (A: 8km, 2.667 km; B: 10 km)
    - Tested 3 microphysical schemes & 3 PBL schemes for 9 simulations in total (Figs. 5 & 8)
  - Droplet collection efficiency from Makkonen [2] based on flow around a cylinder
  - Ice Accretion is an analytical asymptotic model from Brakel et al. [1], based on the solution to the Stefan problem of 1D ice growth.
  - Ablation algorithm was based on a radiation balance between sensible, latent, and radiative fluxes. Radiative fluxes came from WRF while sensible & latent fluxes are calculated. Fluxes are then used to melt or sublimate the ice based upon the ambient temperature.

Loss Estimates

- Site A
  - Individual turbines detected icing between 3% - 47% of the period.
  - During icing only 1% of available potential energy was captured (Fig. 1).
    - Potential energy calculated based on power curve and nacelle wind speed
    - Much of production loss due to turbine being shut down during icing event.
- Site B
  - No icing detector available, most deviation from power curve at T < 0 C (Fig 2).
  - Attributing all loss when temp < 0 C to icing, power production capture rates were:
    - T< -10: 64 % | -10 <= T <0 : 93 % | 0 <= T : 101 %

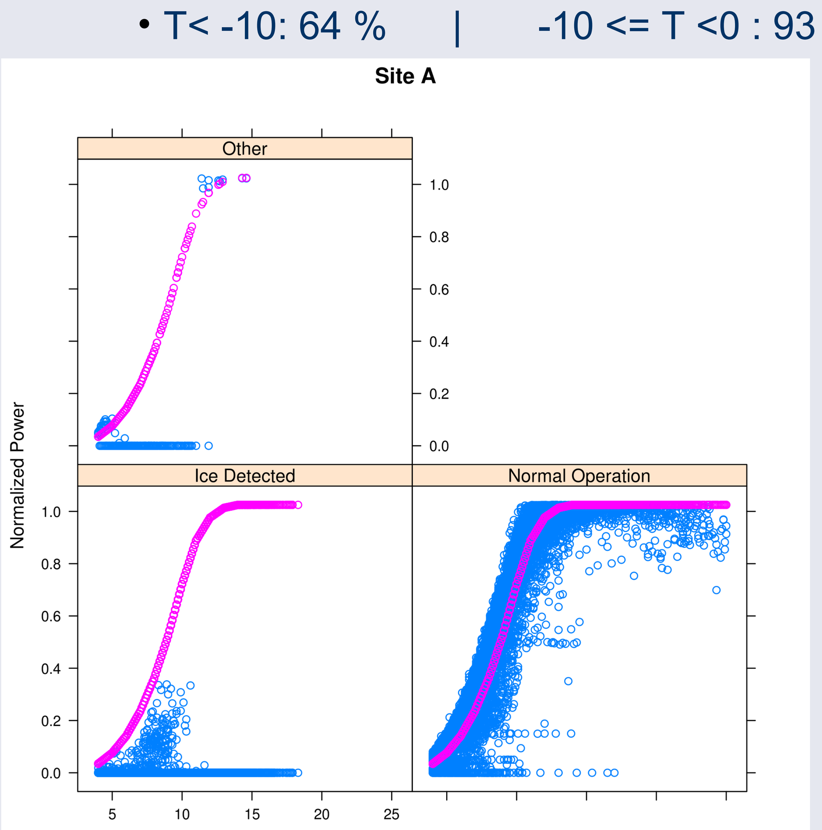

Fig. 1: Observed (Blue) vs estimated (Pink) power production under 3 turbine states at site A. Icing was when the turbine had an icing flag or a load control flag while other turbines had icing flags; Other was all other flag state except normal operation.

Data was filtered to remove wind speeds above and below the cutoff values.

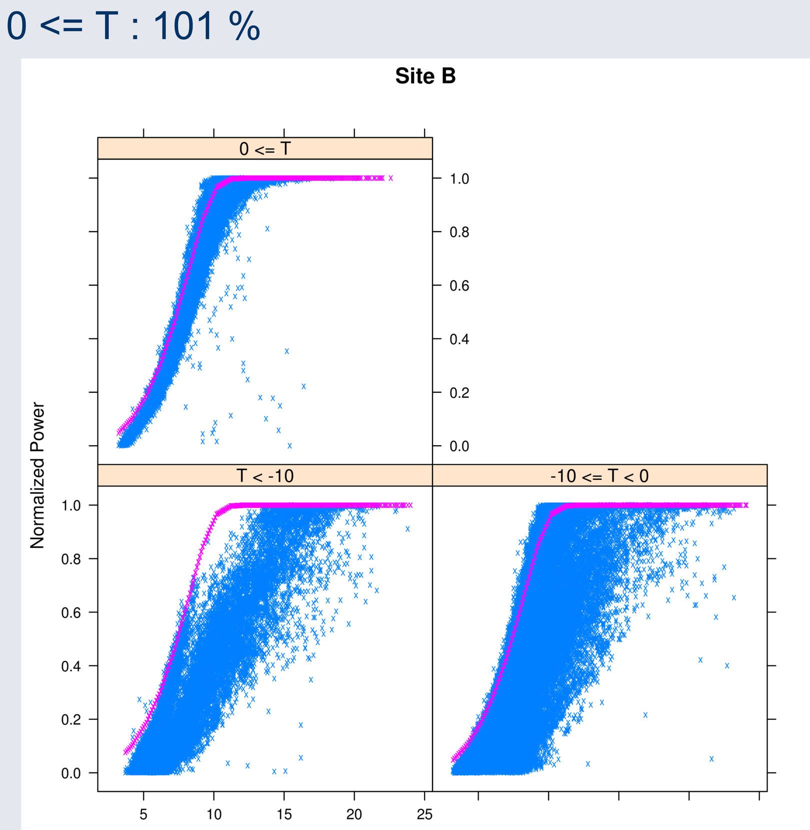

Fig. 2: Observed (Blue) vs estimated (Pink) power production for different temperature bins at site B.

Data was filtered to remove wind speeds above and below the cutoff values, and to remove all times when there was no power production, due to uncertainty of cause of turbine shutdown.

Icing Forecast

Figures 3, 4, 6 & 7 used the Thompson microphysics & MYNN2 PBL scheme options of WRF.

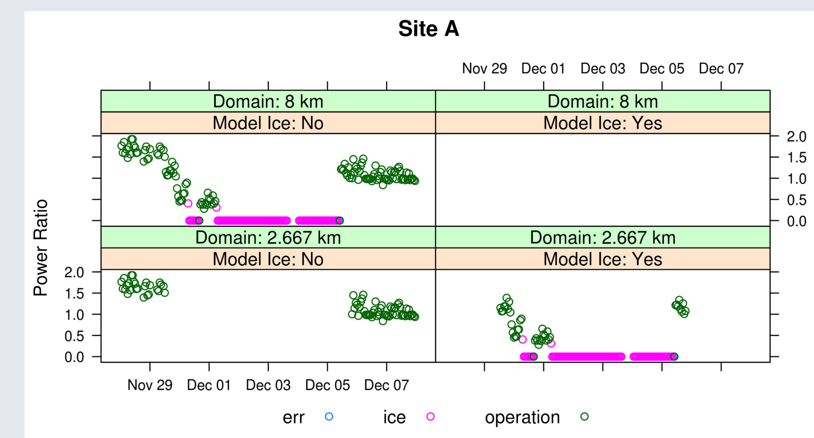

Fig. 3: Power ratio (Actual / Estimated) for 10 day period. Colors indicate turbine alarm state; boxes indicate modeled icing (yes) and domain size.

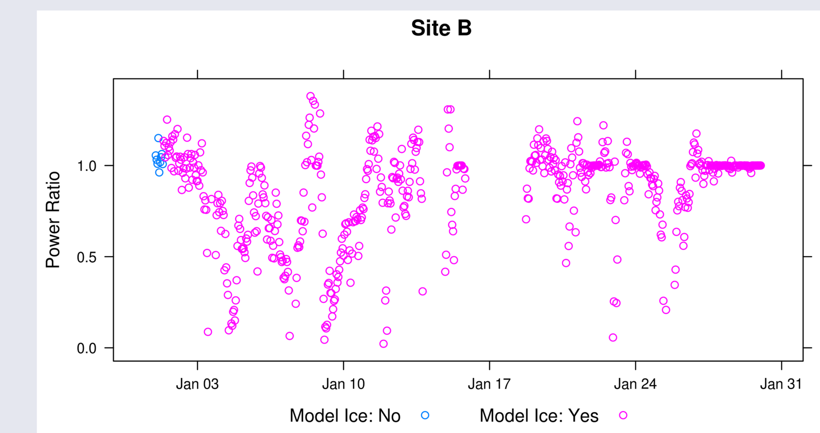

Fig. 6: Power ratio (Actual / Estimated) for January 2011 at site B. Color indicates ice having accumulated in the model.

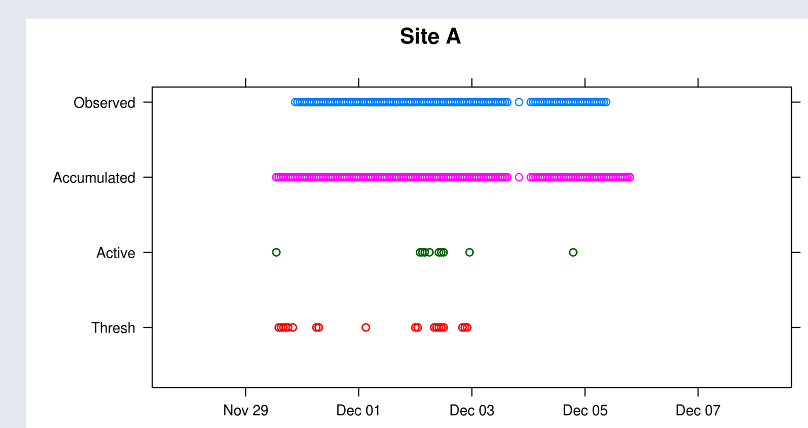

Fig. 4: Periods with icing.
* Observed (Turbine Indicated)
* Accumulated (Output from Model)
* Active (Growth in Model)
* Thresh (Clouds + cold temperatures)

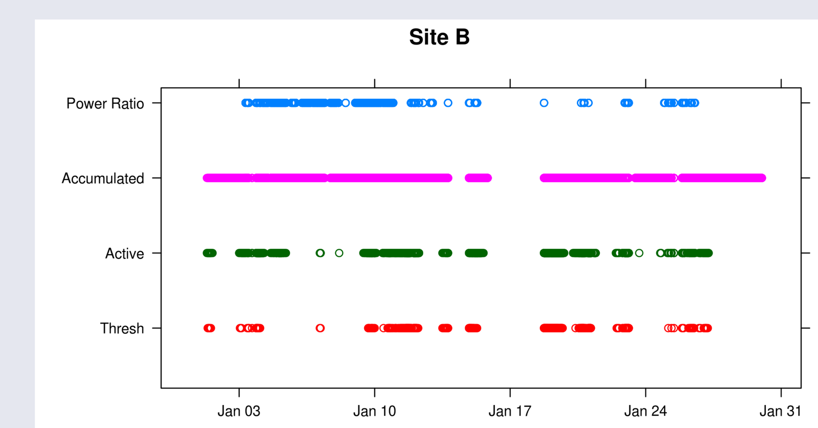

Fig. 7: Periods with icing.
* Power Ratio (T < 0 C and Power Ratio < .8)
* Accumulated (Output from Model)
* Active (Growth in Model)
* Thresh (Clouds + cold temperatures)

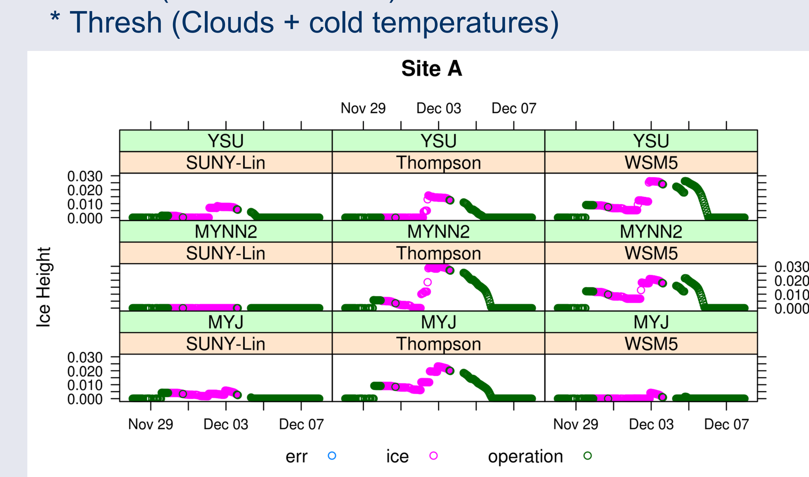

Fig. 5: Modeled ice accumulation (m). Colors indicate observed turbine state. Green labels are PBL schemes, orange labels are mp schemes.

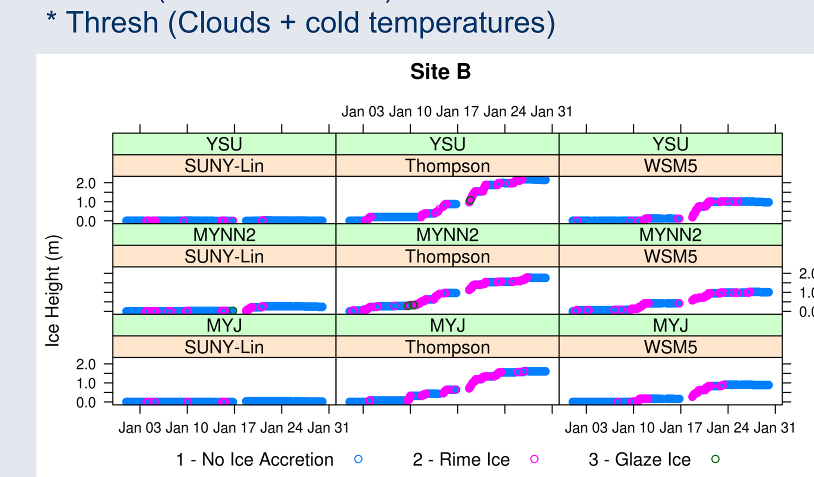

Fig. 8: Modeled ice accumulation. Colors indicate model icing type (accretion). Green labels are PBL schemes, orange labels are mp schemes.

Conclusions

Model does a fairly good job of representing the onset of icing (Fig 1-4) and for the moderate icing event at site A does a good job represent the event in total. At the heavily iced site B, the model does not handle the removal of ice very well growing up to 2m of ice during the month. This is also shown to a lesser extent at site A, where the model does not capture the break in the middle of the event, and it continues to show as iced later than the observations.

In mountainous terrain site A, the model is very sensitive to grid resolution (Fig. 1). At the courser resolution there is no icing forecasted, while at the higher resolution the model shows good performance.

The use of the accumulation model shows definite improvements over just an accretion model, or the threshold method at site A (Fig. 4). At site B the accumulation model over estimates the icing period, while the other methods underestimate the period (Fig. 7). This is due to the fact that the accretion and threshold methods only show when ice is actively growing, not the duration it is on the blades, which can be significant if deicing is not used.

Icing events are shorter lived and smaller in magnitude using the SUNY-Lin microphysical scheme, while WSM5 & Thompson appear to have similar behavior. The PBL schemes can make a large difference in the amount of icing which occurs, as well as when the events begin (Figs 5 & 8).

Future Work

Further investigation of ice ablation mechanisms:
- Introduction of ice shedding model
- Evaluation of heat transfer coefficients
- Enhanced algorithms for sensible and latent heating

Comparison with ISO model for structures. Currently the ISO model is the industry standard model for forecasting icing on turbines, this model needs to be compared against it to show any improvements.

Additional testing of the WRF model including forecast runs, different initial and boundary conditions.

Compare against other sites with icing detectors.

Investigate relationship between ice type, height and power loss, for use in developing an algorithm relating ice parameters to power loss.

Investigate the causes of icing differences within wind parks, and include in the model.

Develop collection efficiency database for airfoils rather than cylinders.

References

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